Spring 2001

Health Hazards of Smoke

USDA Forest Service — Missoula Technology & Development Center

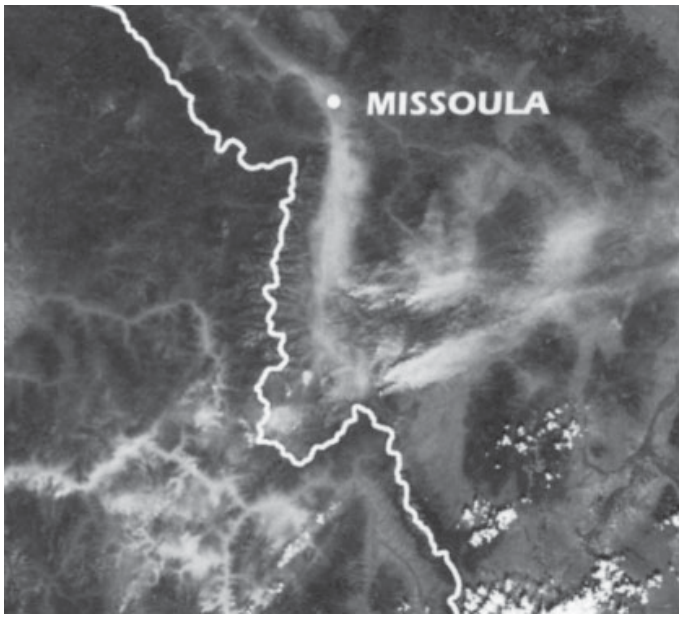
The National Wildfire Coordinating Group (NWCG) coordinates wildland firefighting among Federal and State agencies. The Coordinating Group assigned the Missoula Technology and Development Center (MTDC) to summarize studies on the effects of wildland fire smoke on firefighters. This status report, the 13th in a series, reviews recent exposures of firefighters and citizens to the hazards of smoke from wildfires and presents research on the health effects of exposure.

Fires of 1999

Late summer wildfires on the Shasta-Trinity National Forest, combined with stagnant air, led to numerous local and regional air quality problems. These problems resulted in the first state of emergency declared in a California county because of air pollution, and the first known evacuation based on hazardous air pollution levels. Hourly average levels for particulate smaller than 10 µm (PM_{10}) at the Hoopa monitoring station ranged up to 1,000 µg/m^3, and area stations recorded several days when the 24-hour average PM_{10} levels were higher than 400 µg/m^3. On October 22, 1999, the county emergency services office prepared the following notice:

"The Humboldt County Sheriff's Department Office of Emergency Services is strongly recommending evacuation of the Hoopa, Willow Creek, and all smoke-affected areas due to serious health risks caused by hazardous air quality."

The conditions were reminiscent of those recorded in 1987, the year that led to the NWCG study of the effects of smoke exposure on wildland firefighters. For information on that report, contact MTDC or the publication *Health Hazards of Smoke: Recommendations of the 1997 Consensus Conference*, 9[illegible]2836-1[illegible].



Satellite view of western Montana during a typical day in August 2000.

Fire Storm 2000

The 2000 fire season ranked as one of the worst in the past 50 years. With thousands of fires and over 7 million acres burned, the season strained human and physical resources to the limit. Army, Marine, and National Guard units, as well as firefighting personnel from Canada, Mexico, Australia, and New Zealand assisted firefighters. With the fires came a pall of smoke that blanketed large areas of the Mountain West. While the smoke from the 1988 Yellowstone fires may have been more concentrated, it was isolated and didn't last as long. The smoke from the year 2000 fires in Montana and Idaho accumulated in mountain valleys, affecting the lives and health of thousands of residents.

Air quality is determined by measuring the amount of small particles in the air. Particles

smaller than 10 microns affect air quality, visibility, and health. Montana and Idaho annually average 19 to 24 µg/m^3 (micrograms of particulate per cubic meter of air), well below the U.S. Environmental Protection Agency (EPA) PM_{10} standard of 50 µg/m^3. During August 2000, smoke covered large portions of Montana and Idaho. In Missoula, MT, where the City/County Health Department regularly monitors air quality, 1-hour PM_{10} levels peaked at 550 µg/m^3. Twenty-four hour PM_{10} levels frequently averaged above 100 µg/m^3 and several exceeded 200 µg/m^3.

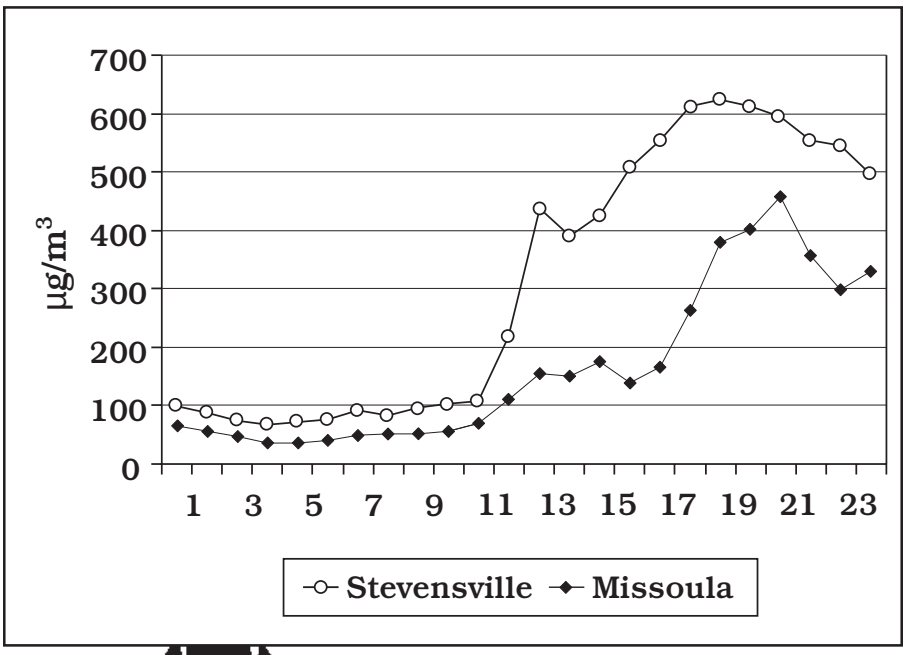


Figure 1—Hourly PM$_{10}$ comparison between Stevensville and Missoula, August 9, 2000. From: Missoula City/County Department of Environmental Health.

Air pollution alerts were common. The EPA 24-hour air quality standard is 150 µg/m^3 (Missoula calls a stage 1 alert when the PM_{10} exceeds 80 µg/m^3). Missoula calls stage 3 alerts when the 24-hour levels approach 300 µg/m^3. Because much of the smoke was coming from the Bitterroot Valley south of Missoula, smoke levels in the valley were usually higher than those recorded in Missoula (figure 1).

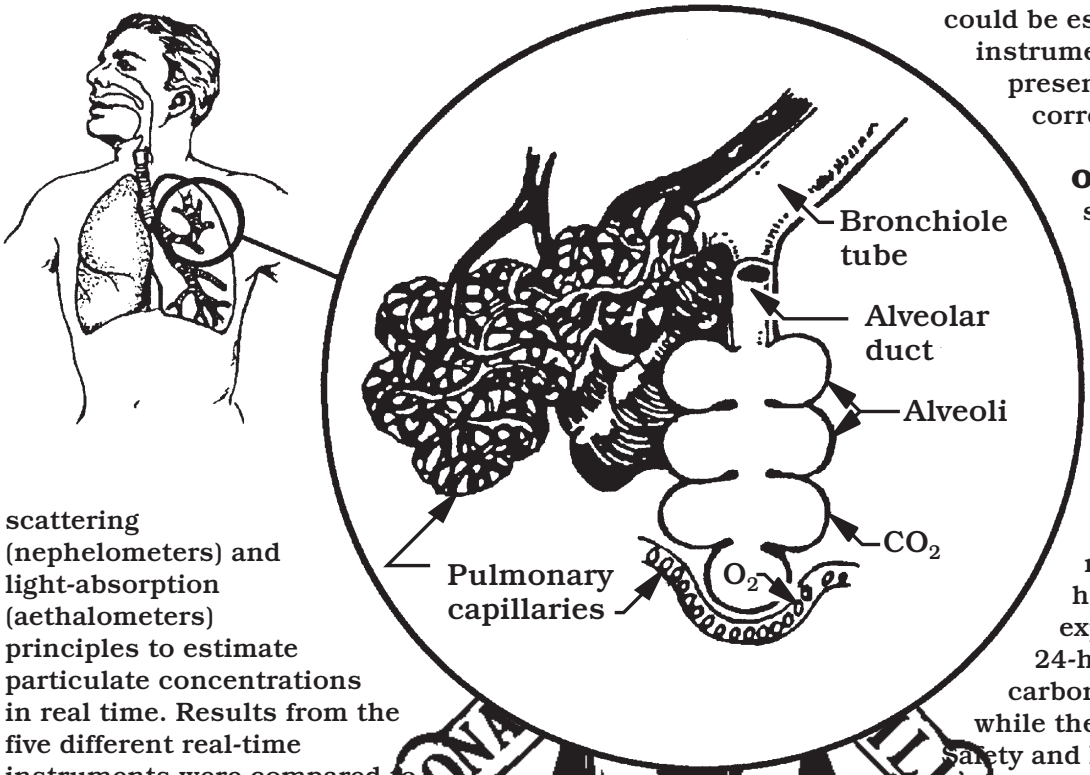
In the Bitterroot Valley, 8-hour averages were higher than 300 µg/m^3 five times and one 1-hour concentration approached 1,000 µg/m^3. A monitor at the Valley Complex fire camp in the southern part of the Bitterroot Valley recorded some 24-hour PM_{10} concentrations greater than 100 µg/m^3. At times the smoke was deep enough to cover the peaks of the Bitterroot Mountains, which rise 6,000 feet above the valley floor.

Salmon, ID, south of the Bitterroot Valley, experienced high levels of smoke exposure from the extensive fires in the area. According to the Idaho Department of Environmental Quality, 24-hour PM_{10} levels measured near local pool in late August exceeded 1,000 µg/m^3 on several occasions. Hourly levels of particulate smaller than 2.5 µm ($PM_{2.5}$) reached 1750 µg/m^3 on one occasion with several readings over 1000 µg/m^3. Hourly $PM_{2.5}$ levels [illegible] exceeded 500 µg/m^3 with several readings over 600 µg/m^3.

Fine Particles—Recent research concerning the adverse health effects of fine particles has led to a proposal for a new EPA standard for $PM_{2.5}$ particulate. The fine particles can be inhaled deep into the lungs where they cause irritation and breathing problems. Larger particles are swept upward by ciliary action and expectorated. Fine particles have the potential to carry carcinogens deep into the respiratory system.

Fine particles constitute a high percentage of total particulate from wood smoke. Long-term exposure to fine particles has been associated with respiratory and cardiovascular illness and death. The $PM_{2.5}$ standard is 15 µg/m^3 for an annual daily average and 65 µg/m^3 for a 24-hour average. Missoula experienced a high of 179 µg/m^3 on the 10th of August. Data collected by MTDC in Hamilton, MT, indicate that $PM_{2.5}$ concentrations were greater than 100 µg/m^3 six times from August 15 to August 29. During at least 2 days, concentrations averaged between 200 and 300 µg/m^3 (figure 2).

The MTDC Watershed, Soil, and Air program conducted a collocation study of real-time particulate monitors in the Missoula and Bitterroot Valleys during Fire Storm 2000. The real-time particulate instruments use particle light-



scattering (nephelometers) and light-absorption (aethalometers) principles to estimate particulate concentrations in real time. Results from the five different real-time instruments were compared to gravimetric results from a collocated Federal Reference Method $PM_{2.5}$ sampler.

Results indicate that the real-time instruments tend to overestimate particulate concentrations, sometimes by more than twice the actual concentration. However, overestimated results were linear over the entire range of particle concentrations less than [illegible] µg/m³ and less than 4[illegible] µg/m³ as calculated by the Federal Reference Method sampler), so correction curves or equations could be established for each instrument. Results presented here represent corrected values.

Other Hazards—The smoke from forest fires contains other hazards, including carbon monoxide, formaldehyde, acrolein, and benzene. Carbon monoxide levels higher than 40 parts per million (ppm) have been recorded during heavy smoke exposures. The EPA 24-hour standard for carbon monoxide is 9 ppm, while the Occupational Safety and Health Administration (OSHA) 8-hour permissible exposure limit is 50 ppm. High levels of carbon monoxide can cause headaches, irritability, and nausea, and they are a risk for individuals with established heart disease (see page 7). Formaldehyde and acrolein cause the eye and respiratory irritation experienced during exposure to smoke. Formaldehyde is a potential carcinogen, but only at levels far above those encountered by wildland firefighters. Benzene becomes a risk for firefighters who regularly work around fuel and engines. Because the concentrations of the different hazards in smoke are correlated, a high level of carbon monoxide suggests elevated levels of particulate and aldehydes.

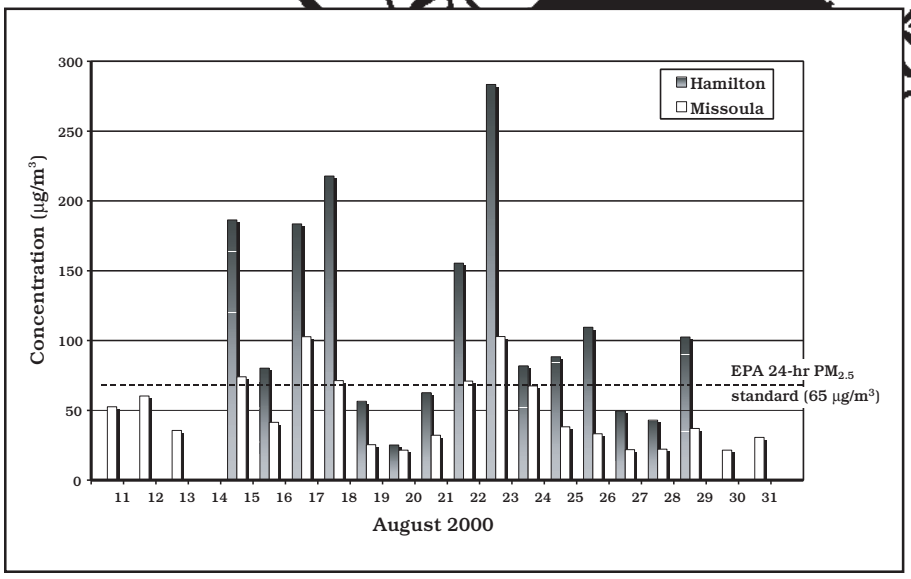


Figure 2—Twenty-four hour average $PM_{2.5}$ concentration at Hamilton and Missoula, MT, during August 2000. From: MTDC Watershed, Soil, and Air program.

Standards Comparison

The EPA recommends air quality standards and monitors compliance. These standards are intended to protect all citizens, including the very young, the elderly, and people with health problems. Accordingly, the EPA standards are set at a level well below the risk to healthy citizens.

Compliance with workplace exposure standards is monitored by OSHA. After extensive review and public comment, proposed standards (permissible exposure limits) are adopted and published. The limits established by OSHA represent conditions that nearly all workers may be exposed to day after day without adverse health effects according to OSHA (figure 3).

Health Hazards of Smoke

The health effects of exposure to smoke from burning vegetation have been studied in a variety of populations, ranging from children to wildland firefighters. This section will focus on the health effects of smoke exposure, including lung function, cardiopulmonary disease, and lung cancer.

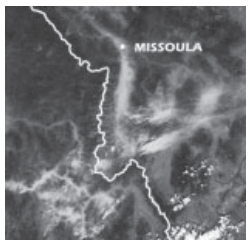
Acute Health Effects—Studies of smoke exposure indicate a relationship between exposure, respiratory symptoms, and respiratory illness. Respiratory symptoms (coughing, wheezing, shortness of breath) increased in a portion of the population exposed to smoke from agricultural burning. Women and people with asthma and chronic bronchitis were more likely to be affected. Although the prolonged Southeast Asian haze episodes (1997 to 1998) were associated with increased hospital visits and asthma symptoms in children, studies of smoke from bushfires in Australia did not detect an increase in emergency hospital visits for asthma during the episodes. Large forest fires in California (1987) led to increased emergency room visits for asthma and chronic obstructive pulmonary disease.

Wildland firefighters may be exposed to particulate levels several times higher than those observed in exposed communities (PM_{10} exposure averaged 690 µg/m³ on wildfires). Surveys of medical records (1989, 1994, and 2000) indicated that 30 to 50 percent of firefighter visits to medical tents are for upper respiratory problems, including coughs, colds, and sore throats. A number of factors in the firefighting environment influence immune function and the body's susceptibility to respiratory problems and other illnesses. Upper respiratory problems can be caused by fatigue, stress, sleep deprivation, poor nutrition, rapid weight loss, exposure to smoke, or a combination of stressors.

Lung Function—Studies of children and firefighters document the effect of smoke exposure on lung (pulmonary) function. When third-, fourth-, and fifth-grade school children were studied in Missoula, MT, elevated levels of suspended particulate were associated with a slight decrease in lung function. The adverse effects of particulate on children's lung function were small, acute, and reversible, with values

Particulate Standards

EPA—PM_{10}	OSHA —PEL*
150 µg/m³—24 hour 50 µg/m³—annual	5,000 µg/m³



*PEL—Eight-hour permissible exposure limit

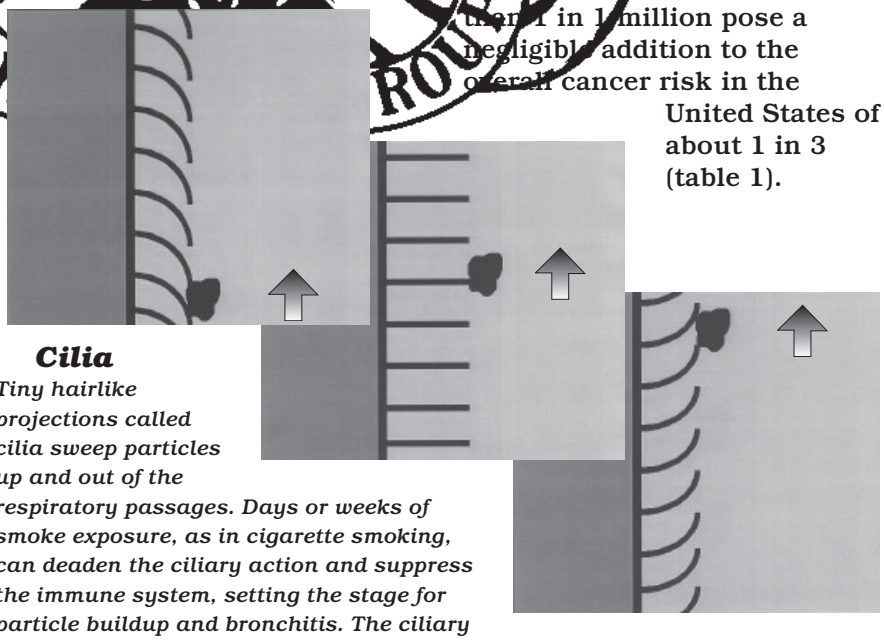
Figure 3 —The EPA 24-hour standard is far below the OSHA 8-hour permissible exposure limit for PM_{10}. The average exposure for wildland firefighters (690 µg/m³) exceeded most community exposures (100 to 500 µg/m³).

returning to normal after 2 months with clean air. Studies of wildland firefighters show small but statistically significant decreases in lung function after a day or a season of firefighting. As with the children, the values returned to preexposure levels after the firefighters were able to breathe clean air. A 4-year study showed that wildland firefighters have above-average lung function and that occupational exposure to smoke has little effect on the decline in lung function that normally occurs with age.

The respiratory system is overbuilt for its duties. Its capacity is one-and-one-half times that needed at maximal effort (for instance 180 L/min compared to 120 L/min at maximal aerobic capacity). So a slight temporary decline in lung function is not noticeable and it does not decrease work performance. The human lung has a remarkable capacity to cleanse itself when given an opportunity. In one study, decreased lung function persisted 16 days—but not 25 days—after exposure to smoke. The significance of transient and apparently reversible effects on lung function, and their possible contribution to permanent functional or structural changes, has not been established.

Chronic Health Effects—Urban pollution has been linked to increased rates of mortality and morbidity. A recent study of five major cities in the United States found that the level of PM_{10} is associated with the rate of death from all causes and from cardiovascular and respiratory causes. The estimated increase in the relative rate of death from cardiovascular and respiratory causes was 0.68 percent for each 10 $\mu g/m^3$ increase in PM_{10}. These results suggest a long-term risk of exposure to fine particulate and strengthen the rationale for controlling the levels of respirable particles.

Lung Cancer—According to the World Health Organization, the data on exposure to vegetative smoke do not support an increase in the risk for lung cancer, even at exposure levels well above those experienced by firefighters. Studies of women in developing countries who cook over unvented stoves indicate that exposure to wood smoke with particulate levels of 850 to 1,400 $\mu g/m^3$ can be associated with chronic lung disease, but not with cancer. Cigarette smokers are subject to a variety of diseases and disorders (such as lung cancer, heart disease, emphysema, and chronic bronchitis) after many years of daily exposure to smoke. However, these exposures are much higher and stronger than exposure to biomass smoke and vegetative



Cilia

Tiny hairlike projections called cilia sweep particles up and out of the respiratory passages. Days or weeks of smoke exposure, as in cigarette smoking, can deaden the ciliary action and suppress the immune system, setting the stage for particle buildup and bronchitis. The ciliary action recovers when the smoke exposure ends.

fires. The smoker's risk of lung cancer is 7 to 14 times higher than the risk associated with long-term exposure to second-hand tobacco smoke. An assessment of chronic smoke exposure for wildland firefighters indicated little increased risk for the average firefighter, even though exposure can be several times higher than that experienced by residents of communities exposed to smoke. While biomass smoke may be a potential carcinogen, it is much less of a cancer risk than motor vehicle exhaust or other known carcinogens. University of Montana chemist Garon Smith analyzed the smoke in the Missoula Valley during the fires of 2000. Smith's studies did not reveal a wildfire-related increase in cancer-causing polycyclic aromatic hydrocarbons.

Oncologists estimate that genetics is a factor in 60 to 90 percent of all cancers. Bad habits, such as tobacco, poor nutrition, and pollution are responsible for the remaining cancers. Cancer risks of less than 1 in 1 million pose a negligible addition to the overall cancer risk in the United States of about 1 in 3 (table 1).

Table 1—Cancer Risks

Activity	Risk/million
Smoking two packs per day	100,000
Radon	20,000
X-ray	7
Type I firefighters	24*
Type II firefighters	3.2*

*Upper limit estimate of the risk of developing cancer for lifetime exposure conditions. Actual risks may be significantly lower due to extrapolations and uncertainties.

Summary

The potential health effects from exposure to the smoke from wildland fires range from:

- Short-term (cough, eye irritation, lung function)
- Intermediate (bronchitis, decreased immune function)
- Long-term risks (lung and heart disease, cancer)

Studies of smoke exposure indicate a relationship between exposure, respiratory symptoms, and respiratory illness. Cigarette smokers have far more exposure and illness than residents exposed to the smoke from vegetative fires. Firefighters who smoke have more carbon monoxide in their blood on the way to the fire than do nonsmoking firefighters at the end of the work shift. While the long-term risks of lung and heart disease and cancer are suggested by studies of smoking and air pollution, these effects have not been confirmed in wildland firefighters.

Respiratory symptoms (coughing, wheezing, and shortness of breath) increase in a portion of the population exposed to smoke. Some studies show an increase in emergency room visits for asthma and chronic obstructive pulmonary disease during episodes of smoke exposure. When physicians specializing in lung disease were interviewed after the smoke exposures of the 2000 fire season, they had the following comments:

"Even subjects with chronic lung conditions had few complications. Most people did remarkably well."

"People with normal, healthy lungs should not have long-term effects." (Missoulian, [illegible], 2000)

In a letter to health officials (August 23, 200[illegible]) the Montana State medical [illegible]er said:

"Alth[illegible]h the [illegible]ct of the poor [illegible]uality [illegible] quite s[illegible]ous for t[illegible] with underly[illegible] [illegible]art and lung disease, this is not true for healthier individua[illegible] T[illegible] no doubt that [illegible] is irrit[illegible] and re[illegible] [illegible]cratch[illegible] dry cou[illegible] irritated [illegible] [illegible]ches and r[illegible] these effec[illegible]

Sources: World Health Organization. 1999. *Health guidelines for vegetation fire events.*

Sharkey, Brian. 1997. *Health hazards of smoke: recommendations of the consensus conference*. April 1997. 9751-2836-MTDC. Missoula, MT.

Johnson, Kit. 1990. *Montana air pollution study: children's health effects. Journal of Official Statistics*, 5: 391.

Samet, J., and others. 2000. Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994. *New England Journal of Medicine*, 343: 1742.

Risk Management

Carbon Monoxide Exposure

In 1998, the National Institute for Occupational Safety and Health (NIOSH) assisted the Colorado Department of Public Health and Environment, the Forest Service, and the Bureau of Land Management in an evaluation of carbon monoxide exposure. Four crews were equipped with carbon monoxide monitors during wildland firefighting activities. The data did not exceed recommended limits for time-weighted average exposure to carbon monoxide. The time-weighted average for 40 exposure periods was 3.48 ppm (ppm ranging from 0.0 to 22 ppm), well below the OSHA permissible exposure limit of 50 ppm. This time-weighted average compares with the 4.1 ppm time-weighted average reported for numerous prescribed fire exposures and wildfire exposures reported by Reinhardt and Ottmar (1997). During 8 of 40 monitoring periods, the carbon monoxide exposure concentrations exceeded the carbon monoxide ceiling limit of 200 ppm. The time-weighted average data indicate that values above 200 ppm were brief because they did not elevate the averages. The highest exposure, 450 ppm, was associated with a time-weighted average of 6 ppm over an 8-hour sampling period. While the health effects of brief, transient exposures are not known and are unlikely to elevate carboxyhemoglobin (COHb) levels significantly, firefighters should try to avoid

high concentrations of smoke during mopup and other tasks associated with exposure to carbon monoxide. (McCammon, J. and McKenzie, L. 1998. *Health Hazards Evaluation Report.* 98-0173-2782. Washington, DC: National Institute of Safety and Health).

Note: Apparently healthy young men can perform upper- and lower-body work at carbon monoxide exposures that result in COHb levels of 20 percent without impairing cardiovascular function (Kizakevich and others, 2000. *European Journal of Applied Physiology*). It takes a carbon monoxide exposure of 200 ppm for 8 hours before COHb levels reach 20 percent (figure 4). A COHb of 20 percent means that 20 percent of the oxygen-carrying capacity of the blood (hemoglobin) is tied up with carbon monoxide. A COHb of 20 percent is equivalent to working at 18,000 feet.

Firefighters' Risks

The MTDC report, *Health Hazards of Smoke: Recommendations of the April 1997 Consensus Conference* (9751-2836-MTDC), includes recommendations for program management, training and tactics, monitoring, health maintenance, respiratory protection, medical surveillance, research, and risk communication.

Because prescribed and wildland fire exposure data found firefighters exceeded OSHA permissible exposure limits in a small percentage of cases (less than 5 percent), considerable attention was given to tactics that would further reduce the risk of exposure. In addition, firefighters were encouraged to practice nutritional and sleep habits that maintain the function of the immune system and minimize the effects of smoke exposure. Factors that impair the immune response include stress, exhaustion, poor nutrition, smoke, loss of sleep, and rapid weight loss. Nutritional strategies include adequate intake of vitamins and antioxidants, a minimum of five servings of fruits and vegetables daily, and solid and liquid carbohydrate supplements during work to maintain lean body weight and energy throughout the fire season. Health habits include washing hands before meals and not sharing water bottles (except in emergencies). Research is underway in the areas of energy and nutrient intake, immune function, and oxidative stress. Results will be reported in *Wildland Firefighter Health and Safety Report*, published twice a year by MTDC.

Citizens' Risks

Residents of communities affected by smoke from wildland fires or prescribed fires are encouraged to practice the recommended health habits. A healthy immune system is the best protection against the effects of smoke. Immune function is enhanced with regular moderate physical activity, good nutrition, hydration, and adequate rest. When smoke is present, residents can use the chart recommended by the Environmental Protection Agency to estimate their risks and guide their behavior (table 2). When smoke is bad, keep windows closed and use air conditioning (when available).

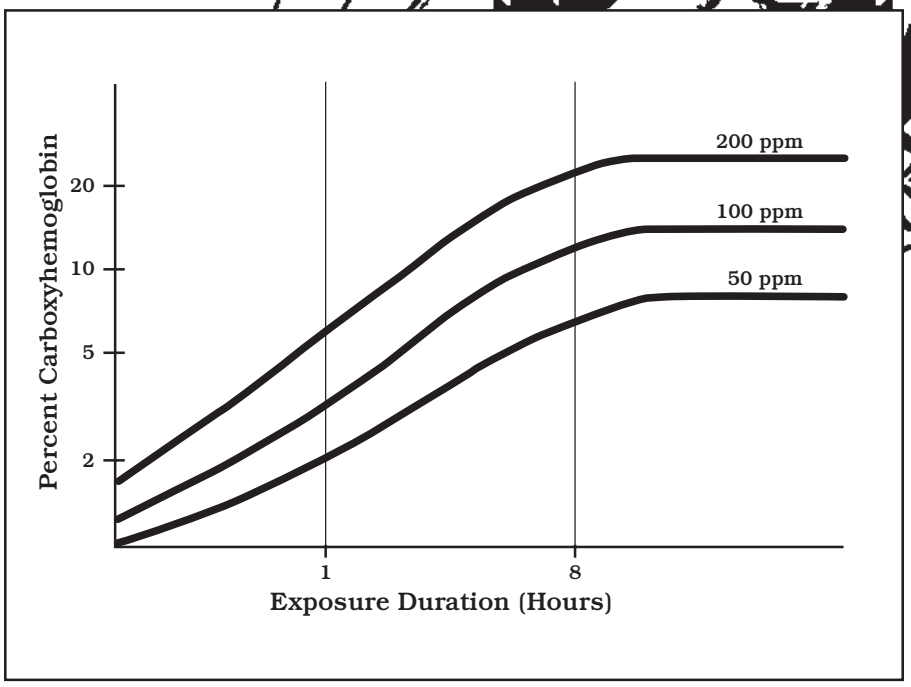


Figure 4—Exposure duration and carboxyhemoglobin levels in the blood.

Finally, residents should keep the risks of exposure in perspective. Life is full of risks. We need to assess them accurately and balance risks and benefits. We know that a motor vehicle fatality occurs every 13 minutes, and that more than 40,000 persons die annually in motor vehicle accidents, so we buckle up and drive carefully to minimize the risk. The risks of occasional exposure to fine particulate and other components of vegetative smoke are minimal for healthy individuals. However, elevated levels of smoke that persist for months or years increase the risk of heart and respiratory disease, especially among the elderly and individuals with preexisting respiratory or cardiovascular illness.

For more information: call MTDC at 406–329–3900, visit our web page (available only on the Forest Service's internal computer network) at *fsweb.mtdc.wo.fs.fed.us* or send e-mail to *bsharkey@fs.fed.us*

Just Released

Smoke Exposure and Hospital Admissions

The Centers for Disease Control and Prevention (CDC) conducted an investigation to determine if increases in respiratory and cardiovascular hospital admissions occurred in four Montana counties during last season's forest fires. The study was released in May 2001. Its goal was to quantify and compare the changes in hospital admission rates from 1999 (when forest fires were not a problem) to 2000 (when they were). The counties included Ravalli, with the highest exposure, Missoula, and Lewis and Clark, both with moderate exposures, and Yellowstone with low exposure. Hourly PM_{10} levels were used to characterize exposures. Hospital admission records were used to represent respiratory and cardiovascular admissions. The study excluded transfers, elective procedures, and admissions of nonresidents. Monthly and 3-month hospitalization rates were calculated for each year by dividing admissions by the 1999 census population for each county. Respiratory disease (chronic obstructive pulmonary disease and pneumonia) and circulatory disease (ischemic heart disease, dysrhythmia, heart failure, and cerebrovascular disease) admissions were evaluated.

Particulate levels were higher during the 12-week period in 2000 than in 1999, with mean PM_{10} levels of 47 $\mu g/m^3$ for Ravalli County, 34.2 $\mu g/m^3$ for Missoula County, and 32.6 $\mu g/m^3$ for Lewis and Clark County. Hospital admission rates for the period (July, August, September) increased in 2000 for respiratory and circulatory problems, and the admissions rates were higher in the high-exposure area. However, when the data were analyzed month-by-month, a temporal exposure-response relationship between particulate levels and hospital admissions was not evident. For example, in Ravalli County the highest increases and rates of hospital admissions for respiratory and circulatory problems occurred in July—before the high smoke exposures of August. Missoula County had fewer admissions for circulatory causes in August, while Yellowstone County, the low exposure area, showed an increase. More work is needed to link hospital admissions to smoke exposure. (from R. Gwynn and J. Mott, 2001 CDC Epi-Aid #2001-07).

Note: This study relied on a single monitor to characterize exposure of an entire county. Biomarkers of smoke exposure will allow a closer link between individual exposures and hospital admissions. The study collected—but did not report—preexisting conditions and smoking data. Residential wood burning and other factors that could confound the relationship between smoke exposure and hospital admissions should be recorded. Future studies should consider alternative hypotheses, such as increased cardiovascular admissions due to anxiety over the potential loss of one's home or summer business, or exertion related to fire control activities. This study reinforces the EPA cautionary statements for individuals with respiratory and heart disease (see table, page 9).

Guidelines for Reporting of Daily Air Quality

[1]Pollutant Standard Index (PSI) for $PM_{2.5}$ 24-Hour

Proposed index categories	Health effects	Cautionary statements	PM_{10}	$PM_{2.5}$	[2]Visibility (miles)
Good	None	None	<40	<15	10+
Moderate	Possibility of aggravation of heart or lung disease among persons with cardiopulmonary disease and the elderly.	None	40 to 79	15 to 64	4 to 9
Unhealthy for sensitive groups	Increasing likelihood of increased respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory and heart disease and the elderly should limit prolonged exertion.	80 to 149	65 to 100	2.5 to 3
Unhealthy	Increasing respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory and heart disease and the elderly should avoid prolonged exertion; everyone else, particularly children, should limit prolonged exertion.	150 to 214	101 to 150	1.25 to 2
Very unhealthy	Significant increase in respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory and heart disease and the elderly should avoid any outdoor activity; everyone else, particularly children, should avoid prolonged exertion.	215 to 354	151 to 250	1
Hazardous	Serious risk of respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	Everyone should avoid any outdoor activity; people with respiratory and heart disease, the elderly, and children should remain indoors.	355+	251 to 350	<0.75

[1] From U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (1998), and the Montana Department of Environmental Quality.

[2] Face away from the sun and look for targets at known distances. Visible range is that point at which even high-contrast objects totally disappear.

Additional single copies of this document may be ordered from:

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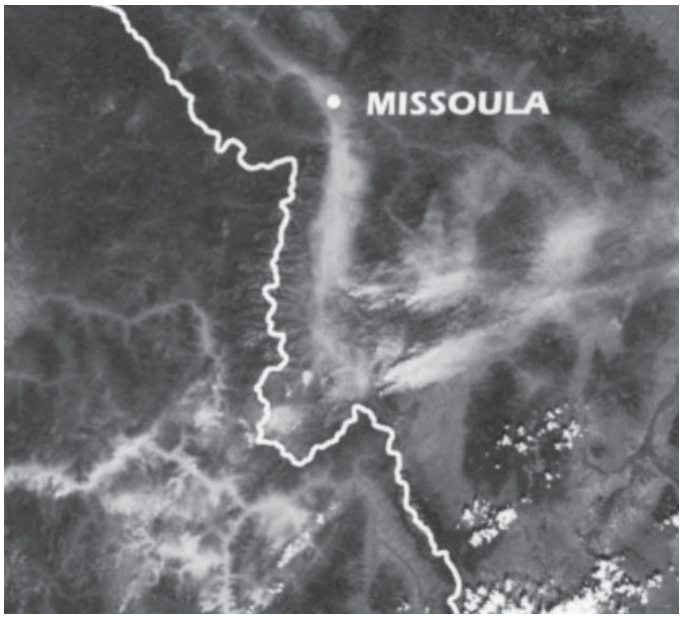
"The Humboldt County Sheriff's Department Office of Emergency Services is strongly recommending evacuation of the Hoopa, Willow Creek, and all smoke-affected areas due to serious health risks caused by hazardous air quality."

The conditions were reminiscent of those recorded in 1987, the year that led to the NWCG study of the effects of smoke exposure on wildland firefighters. For information on that report, contact MTDC or the publication *Health Hazards of Smoke: Recommendations of the 1997 Consensus Conference*, 9[illegible]2836-1[illegible].



Satellite view of western Montana during a typical day in August 2000.

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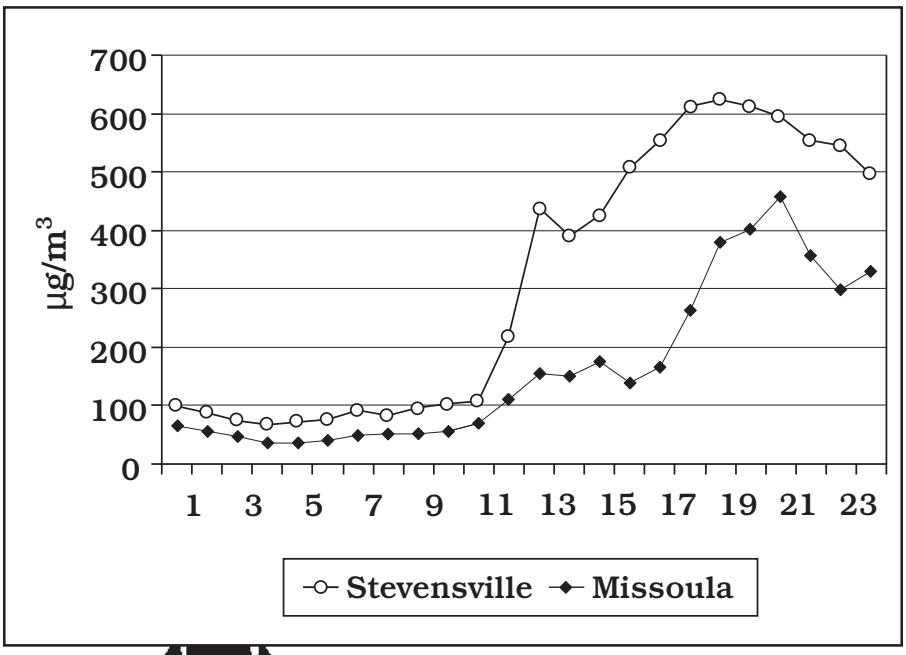


Figure 1—Hourly PM$_{10}$ comparison between Stevensville and Missoula, August 9, 2000. From: Missoula City/County Department of Environmental Health.

Air pollution alerts were common. The EPA 24-hour air quality standard is 150 µg/m^3 (Missoula calls a stage 1 alert when the PM_{10} exceeds 80 µg/m^3). Missoula calls stage 3 alerts when the 24-hour levels approach 300 µg/m^3. Because much of the smoke was coming from the Bitterroot Valley south of Missoula, smoke levels in the valley were usually higher than those recorded in Missoula (figure 1).

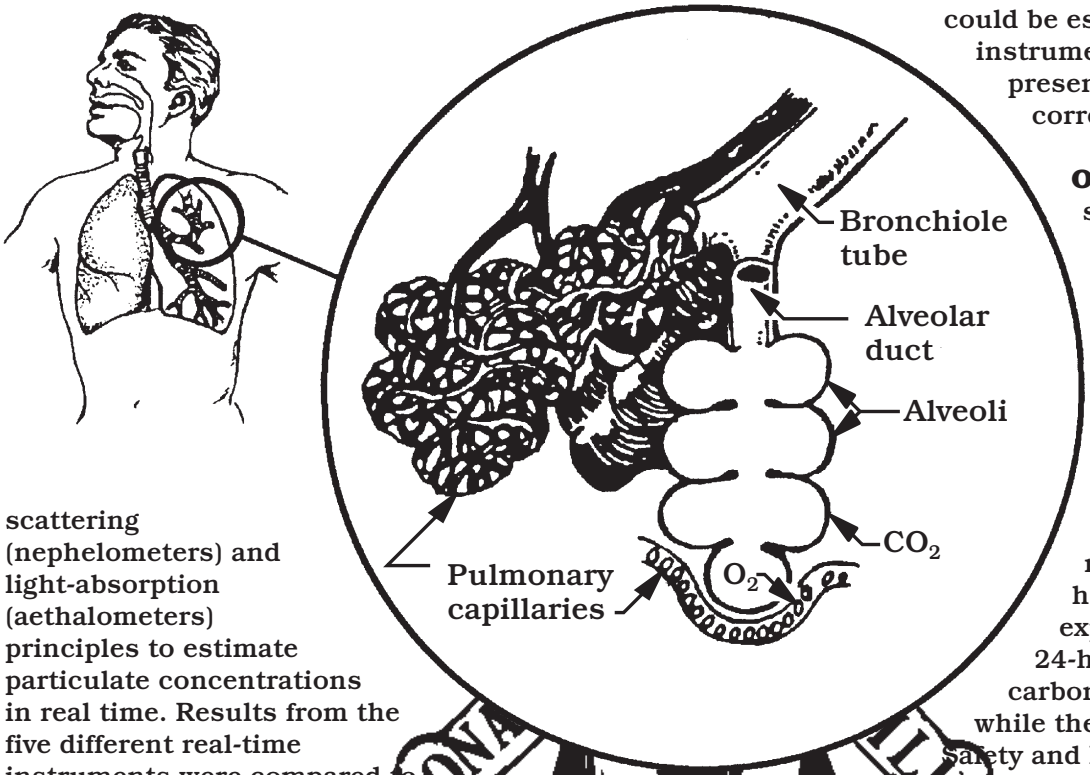
In the Bitterroot Valley, 8-hour averages were higher than 300 µg/m^3 five times and one 1-hour concentration approached 1,000 µg/m^3. A monitor at the Valley Complex fire camp in the southern part of the Bitterroot Valley recorded some 24-hour PM_{10} concentrations greater than 100 µg/m^3. At times the smoke was deep enough to cover the peaks of the Bitterroot Mountains, which rise 6,000 feet above the valley floor.

Salmon, ID, south of the Bitterroot Valley, experienced high levels of smoke exposure from the extensive fires in the area. According to the Idaho Department of Environmental Quality, 24-hour PM_{10} levels measured near local pool in late August exceeded 1,000 µg/m^3 on several occasions. Hourly levels of particulate smaller than 2.5 µm ($PM_{2.5}$) reached 1750 µg/m^3 on one occasion with several readings over 1000 µg/m^3. Hourly $PM_{2.5}$ levels [illegible] exceeded 500 µg/m^3 with several readings over 600 µg/m^3.

Fine Particles—Recent research concerning the adverse health effects of fine particles has led to a proposal for a new EPA standard for $PM_{2.5}$ particulate. The fine particles can be inhaled deep into the lungs where they cause irritation and breathing problems. Larger particles are swept upward by ciliary action and expectorated. Fine particles have the potential to carry carcinogens deep into the respiratory system.

Fine particles constitute a high percentage of total particulate from wood smoke. Long-term exposure to fine particles has been associated with respiratory and cardiovascular illness and death. The $PM_{2.5}$ standard is 15 µg/m^3 for an annual daily average and 65 µg/m^3 for a 24-hour average. Missoula experienced a high of 179 µg/m^3 on the 10th of August. Data collected by MTDC in Hamilton, MT, indicate that $PM_{2.5}$ concentrations were greater than 100 µg/m^3 six times from August 15 to August 29. During at least 2 days, concentrations averaged between 200 and 300 µg/m^3 (figure 2).

The MTDC Watershed, Soil, and Air program conducted a collocation study of real-time particulate monitors in the Missoula and Bitterroot Valleys during Fire Storm 2000. The real-time particulate instruments use particle light-



scattering (nephelometers) and light-absorption (aethalometers) principles to estimate particulate concentrations in real time. Results from the five different real-time instruments were compared to gravimetric results from a collocated Federal Reference Method $PM_{2.5}$ sampler.

Results indicate that the real-time instruments tend to overestimate particulate concentrations, sometimes by more than twice the actual concentration. However, overestimated results were linear over the entire range of particle concentrations less than [illegible] µg/m³ and less than 4[illegible] µg/m³ as calculated by the Federal Reference Method sampler), so correction curves or equations could be established for each instrument. Results presented here represent corrected values.

Other Hazards—The smoke from forest fires contains other hazards, including carbon monoxide, formaldehyde, acrolein, and benzene. Carbon monoxide levels higher than 40 parts per million (ppm) have been recorded during heavy smoke exposures. The EPA 24-hour standard for carbon monoxide is 9 ppm, while the Occupational Safety and Health Administration (OSHA) 8-hour permissible exposure limit is 50 ppm. High levels of carbon monoxide can cause headaches, irritability, and nausea, and they are a risk for individuals with established heart disease (see page 7). Formaldehyde and acrolein cause the eye and respiratory irritation experienced during exposure to smoke. Formaldehyde is a potential carcinogen, but only at levels far above those encountered by wildland firefighters. Benzene becomes a risk for firefighters who regularly work around fuel and engines. Because the concentrations of the different hazards in smoke are correlated, a high level of carbon monoxide suggests elevated levels of particulate and aldehydes.

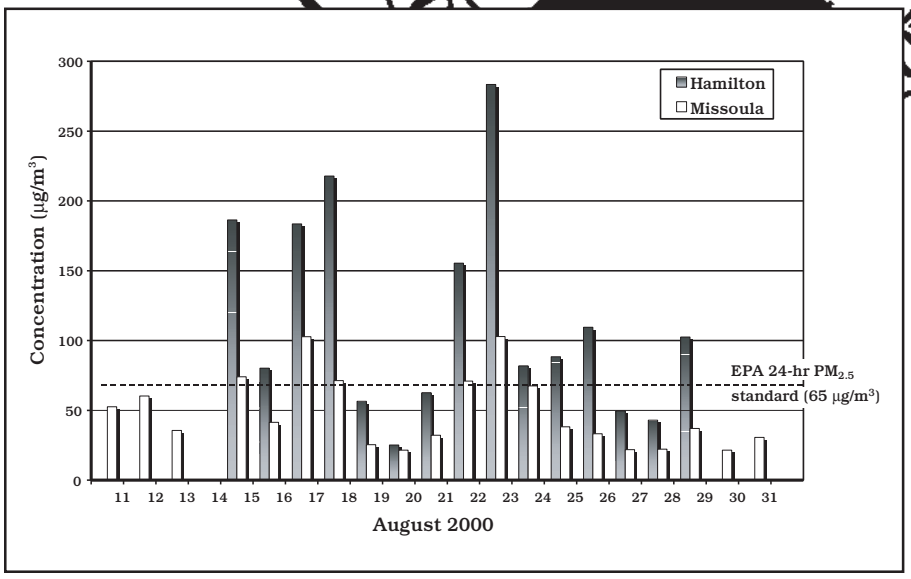


Figure 2—Twenty-four hour average $PM_{2.5}$ concentration at Hamilton and Missoula, MT, during August 2000. From: MTDC Watershed, Soil, and Air program.

Standards Comparison

The EPA recommends air quality standards and monitors compliance. These standards are intended to protect all citizens, including the very young, the elderly, and people with health problems. Accordingly, the EPA standards are set at a level well below the risk to healthy citizens.

Compliance with workplace exposure standards is monitored by OSHA. After extensive review and public comment, proposed standards (permissible exposure limits) are adopted and published. The limits established by OSHA represent conditions that nearly all workers may be exposed to day after day without adverse health effects according to OSHA (figure 3).

Health Hazards of Smoke

The health effects of exposure to smoke from burning vegetation have been studied in a variety of populations, ranging from children to wildland firefighters. This section will focus on the health effects of smoke exposure, including lung function, cardiopulmonary disease, and lung cancer.

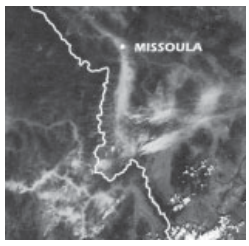
Acute Health Effects—Studies of smoke exposure indicate a relationship between exposure, respiratory symptoms, and respiratory illness. Respiratory symptoms (coughing, wheezing, shortness of breath) increased in a portion of the population exposed to smoke from agricultural burning. Women and people with asthma and chronic bronchitis were more likely to be affected. Although the prolonged Southeast Asian haze episodes (1997 to 1998) were associated with increased hospital visits and asthma symptoms in children, studies of smoke from bushfires in Australia did not detect an increase in emergency hospital visits for asthma during the episodes. Large forest fires in California (1987) led to increased emergency room visits for asthma and chronic obstructive pulmonary disease.

Wildland firefighters may be exposed to particulate levels several times higher than those observed in exposed communities (PM_{10} exposure averaged 690 µg/m³ on wildfires). Surveys of medical records (1989, 1994, and 2000) indicated that 30 to 50 percent of firefighter visits to medical tents are for upper respiratory problems, including coughs, colds, and sore throats. A number of factors in the firefighting environment influence immune function and the body's susceptibility to respiratory problems and other illnesses. Upper respiratory problems can be caused by fatigue, stress, sleep deprivation, poor nutrition, rapid weight loss, exposure to smoke, or a combination of stressors.

Lung Function—Studies of children and firefighters document the effect of smoke exposure on lung (pulmonary) function. When third-, fourth-, and fifth-grade school children were studied in Missoula, MT, elevated levels of suspended particulate were associated with a slight decrease in lung function. The adverse effects of particulate on children's lung function were small, acute, and reversible, with values

Particulate Standards

EPA—PM_{10}	OSHA —PEL*
150 µg/m³—24 hour 50 µg/m³—annual	5,000 µg/m³



*PEL—Eight-hour permissible exposure limit

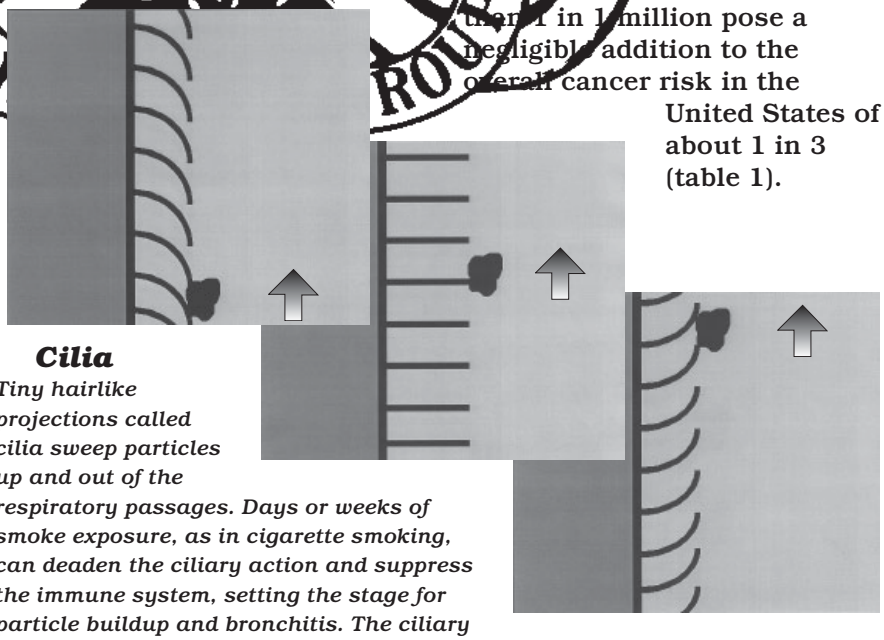
Figure 3 —The EPA 24-hour standard is far below the OSHA 8-hour permissible exposure limit for PM_{10}. The average exposure for wildland firefighters (690 µg/m³) exceeded most community exposures (100 to 500 µg/m³).

returning to normal after 2 months with clean air. Studies of wildland firefighters show small but statistically significant decreases in lung function after a day or a season of firefighting. As with the children, the values returned to preexposure levels after the firefighters were able to breathe clean air. A 4-year study showed that wildland firefighters have above-average lung function and that occupational exposure to smoke has little effect on the decline in lung function that normally occurs with age.

The respiratory system is overbuilt for its duties. Its capacity is one-and-one-half times that needed at maximal effort (for instance 180 L/min compared to 120 L/min at maximal aerobic capacity). So a slight temporary decline in lung function is not noticeable and it does not decrease work performance. The human lung has a remarkable capacity to cleanse itself when given an opportunity. In one study, decreased lung function persisted 16 days—but not 25 days—after exposure to smoke. The significance of transient and apparently reversible effects on lung function, and their possible contribution to permanent functional or structural changes, has not been established.

Chronic Health Effects—Urban pollution has been linked to increased rates of mortality and morbidity. A recent study of five major cities in the United States found that the level of PM_{10} is associated with the rate of death from all causes and from cardiovascular and respiratory causes. The estimated increase in the relative rate of death from cardiovascular and respiratory causes was 0.68 percent for each 10 $\mu g/m^3$ increase in PM_{10}. These results suggest a long-term risk of exposure to fine particulate and strengthen the rationale for controlling the levels of respirable particles.

Lung Cancer—According to the World Health Organization, the data on exposure to vegetative smoke do not support an increase in the risk for lung cancer, even at exposure levels well above those experienced by firefighters. Studies of women in developing countries who cook over unvented stoves indicate that exposure to wood smoke with particulate levels of 850 to 1,400 $\mu g/m^3$ can be associated with chronic lung disease, but not with cancer. Cigarette smokers are subject to a variety of diseases and disorders (such as lung cancer, heart disease, emphysema, and chronic bronchitis) after many years of daily exposure to smoke. However, these exposures are much higher and stronger than exposure to biomass smoke and vegetative



Cilia

Tiny hairlike projections called cilia sweep particles up and out of the respiratory passages. Days or weeks of smoke exposure, as in cigarette smoking, can deaden the ciliary action and suppress the immune system, setting the stage for particle buildup and bronchitis. The ciliary action recovers when the smoke exposure ends.

fires. The smoker's risk of lung cancer is 7 to 14 times higher than the risk associated with long-term exposure to second-hand tobacco smoke. An assessment of chronic smoke exposure for wildland firefighters indicated little increased risk for the average firefighter, even though exposure can be several times higher than that experienced by residents of communities exposed to smoke. While biomass smoke may be a potential carcinogen, it is much less of a cancer risk than motor vehicle exhaust or other known carcinogens. University of Montana chemist Garon Smith analyzed the smoke in the Missoula Valley during the fires of 2000. Smith's studies did not reveal a wildfire-related increase in cancer-causing polycyclic aromatic hydrocarbons.

Oncologists estimate that genetics is a factor in 60 to 90 percent of all cancers. Bad habits, such as tobacco, poor nutrition, and pollution are responsible for the remaining cancers. Cancer risks of less than 1 in 1 million pose a negligible addition to the overall cancer risk in the United States of about 1 in 3 (table 1).

Table 1—Cancer Risks

Activity	Risk/million
Smoking two packs per day	100,000
Radon	20,000
X-ray	7
Type I firefighters	24*
Type II firefighters	3.2*

*Upper limit estimate of the risk of developing cancer for lifetime exposure conditions. Actual risks may be significantly lower due to extrapolations and uncertainties.

Summary

The potential health effects from exposure to the smoke from wildland fires range from:

- Short-term (cough, eye irritation, lung function)
- Intermediate (bronchitis, decreased immune function)
- Long-term risks (lung and heart disease, cancer)

Studies of smoke exposure indicate a relationship between exposure, respiratory symptoms, and respiratory illness. Cigarette smokers have far more exposure and illness than residents exposed to the smoke from vegetative fires. Firefighters who smoke have more carbon monoxide in their blood on the way to the fire than do nonsmoking firefighters at the end of the work shift. While the long-term risks of lung and heart disease and cancer are suggested by studies of smoking and air pollution, these effects have not been confirmed in wildland firefighters.

Respiratory symptoms (coughing, wheezing, and shortness of breath) increase in a portion of the population exposed to smoke. Some studies show an increase in emergency room visits for asthma and chronic obstructive pulmonary disease during episodes of smoke exposure. When physicians specializing in lung disease were interviewed after the smoke exposures of the 2000 fire season, they had the following comments:

"Even subjects with chronic lung conditions had few complications. Most people did remarkably well."

"People with normal, healthy lungs should n[illegible] have long-term effects." (Missoulian, [illegible] 21, 2000)

In a letter to health officials (August 23, 200[illegible] the Montana State [illegible]edical [illegible]er sai[illegible]

"Alth[illegible]h the [illegible]ct of [illegible]e poo[illegible]ualit[illegible] quite s[illegible]ous for t[illegible] with underly[illegible]art and lung disease, this is not tr[illegible] for healthier individua[illegible] [illegible] no doubt that [illegible]e is irri[illegible] and r[illegible] [illegible]ypratch[illegible]dry co[illegible] [illegible]ritated [illegible]s [illegible]ches [illegible] and [illegible] these [illegible]

Sources: World Health Organization. 1999. *Health guidelines for vegetation fire events.*

Sharkey, Brian. 1997. *Health hazards of smoke: recommendations of the consensus conference.* April 1997. 9751-2836-MTDC. Missoula, MT.

Johnson, Kit. 1990. *Montana air pollution study: children's health effects. Journal of Official Statistics*, 5: 391.

Samet, J., and others. 2000. Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994. *New England Journal of Medicine*, 343: 1742.

Risk Management

Carbon Monoxide Exposure

In 1998, the National Institute for Occupational Safety and Health (NIOSH) assisted the Colorado Department of Public Health and Environment, the Forest Service, and the Bureau of Land Management in an evaluation of carbon monoxide exposure. Four crews were equipped with carbon monoxide monitors during wildland firefighting activities. The data did not exceed recommended limits for time-weighted average exposure to carbon monoxide. The time-weighted average for 40 exposure periods was 3.48 ppm (ppm ranging from 0.0 to 22 ppm), well below the OSHA permissible exposure limit of 50 ppm. This time-weighted average compares with the 4.1 ppm time-weighted average reported for numerous prescribed fire exposures and wildfire exposures reported by Reinhardt and Ottmar (1997). During 8 of 40 monitoring periods, the carbon monoxide exposure concentrations exceeded the carbon monoxide ceiling limit of 200 ppm. The time-weighted average data indicate that values above 200 ppm were brief because they did not elevate the averages. The highest exposure, 450 ppm, was associated with a time-weighted average of 6 ppm over an 8-hour sampling period. While the health effects of brief, transient exposures are not known and are unlikely to elevate carboxyhemoglobin (COHb) levels significantly, firefighters should try to avoid

high concentrations of smoke during mopup and other tasks associated with exposure to carbon monoxide. (McCammon, J. and McKenzie, L. 1998. *Health Hazards Evaluation Report.* 98-0173-2782. Washington, DC: National Institute of Safety and Health).

Note: Apparently healthy young men can perform upper- and lower-body work at carbon monoxide exposures that result in COHb levels of 20 percent without impairing cardiovascular function (Kizakevich and others, 2000. *European Journal of Applied Physiology*). It takes a carbon monoxide exposure of 200 ppm for 8 hours before COHb levels reach 20 percent (figure 4). A COHb of 20 percent means that 20 percent of the oxygen-carrying capacity of the blood (hemoglobin) is tied up with carbon monoxide. A COHb of 20 percent is equivalent to working at 18,000 feet.

Firefighters' Risks

The MTDC report, *Health Hazards of Smoke: Recommendations of the April 1997 Consensus Conference* (9751-2836-MTDC), includes recommendations for program management, training and tactics, monitoring, health maintenance, respiratory protection, medical surveillance, research, and risk communication.

Because prescribed and wildland fire exposure data found firefighters exceeded OSHA permissible exposure limits in a small percentage of cases (less than 5 percent), considerable attention was given to tactics that would further reduce the risk of exposure. In addition, firefighters were encouraged to practice nutritional and sleep habits that maintain the function of the immune system and minimize the effects of smoke exposure. Factors that impair the immune response include stress, exhaustion, poor nutrition, smoke, loss of sleep, and rapid weight loss. Nutritional strategies include adequate intake of vitamins and antioxidants, a minimum of five servings of fruits and vegetables daily, and solid and liquid carbohydrate supplements during work to maintain lean body weight and energy throughout the fire season. Health habits include washing hands before meals and not sharing water bottles (except in emergencies). Research is underway in the areas of energy and nutrient intake, immune function, and oxidative stress. Results will be reported in *Wildland Firefighter Health and Safety Report*, published twice a year by MTDC.

Citizens' Risks

Residents of communities affected by smoke from wildland fires or prescribed fires are encouraged to practice the recommended health habits. A healthy immune system is the best protection against the effects of smoke. Immune function is enhanced with regular moderate physical activity, good nutrition, hydration, and adequate rest. When smoke is present, residents can use the chart recommended by the Environmental Protection Agency to estimate their risks and guide their behavior (table 2). When smoke is bad, keep windows closed and use air conditioning (when available).

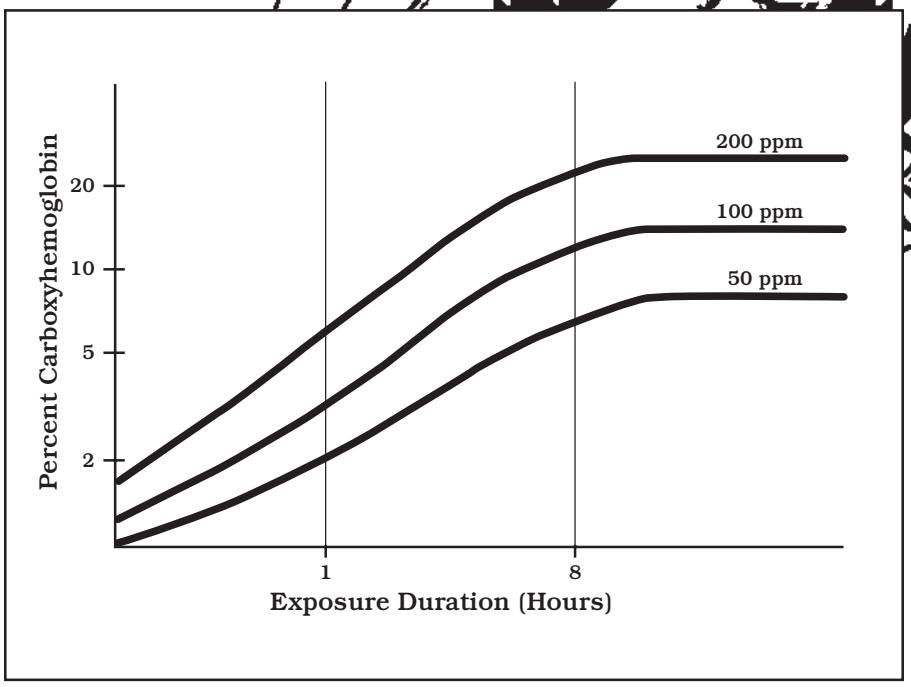


Figure 4—Exposure duration and carboxyhemoglobin levels in the blood.

Finally, residents should keep the risks of exposure in perspective. Life is full of risks. We need to assess them accurately and balance risks and benefits. We know that a motor vehicle fatality occurs every 13 minutes, and that more than 40,000 persons die annually in motor vehicle accidents, so we buckle up and drive carefully to minimize the risk. The risks of occasional exposure to fine particulate and other components of vegetative smoke are minimal for healthy individuals. However, elevated levels of smoke that persist for months or years increase the risk of heart and respiratory disease, especially among the elderly and individuals with preexisting respiratory or cardiovascular illness.

For more information: call MTDC at 406–329–3900, visit our web page (available only on the Forest Service's internal computer network) at *fsweb.mtdc.wo.fs.fed.us* or send e-mail to *bsharkey@fs.fed.us*

Just Released

Smoke Exposure and Hospital Admissions

The Centers for Disease Control and Prevention (CDC) conducted an investigation to determine if increases in respiratory and cardiovascular hospital admissions occurred in four Montana counties during last season's forest fires. The study was released in May 2001. Its goal was to quantify and compare the changes in hospital admission rates from 1999 (when forest fires were not a problem) to 2000 (when they were). The counties included Ravalli, with the highest exposure, Missoula, and Lewis and Clark, both with moderate exposures, and Yellowstone with low exposure. Hourly PM_{10} levels were used to characterize exposures. Hospital admission records were used to represent respiratory and cardiovascular admissions. The study excluded transfers, elective procedures, and admissions of nonresidents. Monthly and 3-month hospitalization rates were calculated for each year by dividing admissions by the 1999 census population for each county. Respiratory disease (chronic obstructive pulmonary disease and pneumonia) and circulatory disease (ischemic heart disease, dysrhythmia, heart failure, and cerebrovascular disease) admissions were evaluated.

Particulate levels were higher during the 12-week period in 2000 than in 1999, with mean PM_{10} levels of 47 $\mu g/m^3$ for Ravalli County, 34.2 $\mu g/m^3$ for Missoula County, and 32.6 $\mu g/m^3$ for Lewis and Clark County. Hospital admission rates for the period (July, August, September) increased in 2000 for respiratory and circulatory problems, and the admissions rates were higher in the high-exposure area. However, when the data were analyzed month-by-month, a temporal exposure-response relationship between particulate levels and hospital admissions was not evident. For example, in Ravalli County the highest increases and rates of hospital admissions for respiratory and circulatory problems occurred in July—before the high smoke exposures of August. Missoula County had fewer admissions for circulatory causes in August, while Yellowstone County, the low exposure area, showed an increase. More work is needed to link hospital admissions to smoke exposure. (from R. Gwynn and J. Mott, 2001 CDC Epi-Aid #2001-07).

Note: This study relied on a single monitor to characterize exposure of an entire county. Biomarkers of smoke exposure will allow a closer link between individual exposures and hospital admissions. The study collected—but did not report—preexisting conditions and smoking data. Residential wood burning and other factors that could confound the relationship between smoke exposure and hospital admissions should be recorded. Future studies should consider alternative hypotheses, such as increased cardiovascular admissions due to anxiety over the potential loss of one's home or summer business, or exertion related to fire control activities. This study reinforces the EPA cautionary statements for individuals with respiratory and heart disease (see table, page 9).

Guidelines for Reporting of Daily Air Quality

[1]Pollutant Standard Index (PSI) for $PM_{2.5}$ 24-Hour

Proposed index categories	Health effects	Cautionary statements	PM_{10}	$PM_{2.5}$	[2]Visibility (miles)
Good	None	None	<40	<15	10+
Moderate	Possibility of aggravation of heart or lung disease among persons with cardiopulmonary disease and the elderly.	None	40 to 79	15 to 64	4 to 9
Unhealthy for sensitive groups	Increasing likelihood of increased respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory and heart disease and the elderly should limit prolonged exertion.	80 to 149	65 to 100	2.5 to 3
Unhealthy	Increasing respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory and heart disease and the elderly should avoid prolonged exertion; everyone else, particularly children, should limit prolonged exertion.	150 to 214	101 to 150	1.25 to 2
Very unhealthy	Significant increase in respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory and heart disease and the elderly should avoid any outdoor activity; everyone else, particularly children, should avoid prolonged exertion.	215 to 354	151 to 250	1
Hazardous	Serious risk of respiratory symptoms in children and adults, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	Everyone should avoid any outdoor activity; people with respiratory and heart disease, the elderly, and children should remain indoors.	355+	251 to 350	<0.75

[1] From U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (1998), and the Montana Department of Environmental Quality.

[2] Face away from the sun and look for targets at known distances. Visible range is that point at which even high-contrast objects totally disappear.

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